IDENTIFICATION OF METHODS, PROCEDURES AND REGULATIONS RELATING TO THE CLOSURE OF DUMPS AND SANITARY LANDFILLS

Submitted to

THE NEW BRUNSWICK

DEPARTMENT OF THE ENVIRONMENT

Prepared by

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Dear Mr. Lutes:

Owen Washburn Associates Ltd. is pleased to submit five copies of our final report on the closure of landfills. The study provides an overview of current regulations, practices and procedures used in the closure of waste disposal sites. It also identifies several mechanisms for developing a registry of closed sites.

We were pleased to have had an opportunity to work on this interesting project and look forward to working with the department in the future.

Yours very truly,

Owen Washburn

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TABLE OF CONTENTS

	Page
Letter of Transmittal	i
Table of Contents	ii
1.0 INTRODUCTION	1-1
2.0 LITERATURE REVIEW OF ISSUES RELATING TO THE CLOSURE OF LANDFILLS	2-1
2.1 Scope of the Review	2-1
2.2 Closure Issues Revealed in the Literature Review	2-2
2.2.1 Closure and Post Closure Planning	2-3
2.2.2 Leachate Control	2-4
2.2.3 Control of Methane Gas	2-9
2.2.3.1 Methane Gas Generation	2-9
2.2.3.2 Passive Methane Control Systems	2-12
2.2.3.3 Active Methane Control Systems	2-13
2.2.4 Final Cover and Cap Design	2-14
2.2.4.1 Role of Covers in Landfill Closures	2-14
2.2.4.2 Factors Considered in Cover Design	2-15
2.2.4.3 Structural Components of a Cover	2-21
2.2.5 Cost of Closure	2-26
2.2.5.1 Closure Costs	2-27
2.2.5.2 Post Closure Costs	2-31

Page

2.2.6 Land-Use Restrictions 2-32

2.2.6.1 Conventional Land-Use 2-32

2.2.6.2 Landfill Reclamation 2-36

3.0 REVIEW OF SANITARY LANDFILL CLOSURE REGULATIONS IN OTHER JURISDICTIONS 3-1

3.1 Elements of Closure Regulations 3-3

3.2 Regulations for the Closure of Sanitary Landfills 3-7

3.2.1 Illinois Environmental Protection Agency . 3-7

3.2.2 Maine Department of Environmental Protection 3-14

3.2.3 New York Department of Environmental Conservation 3-21

3.2.4 Canadian Jurisdictions 3-27

3.2.5 Final Cover Specifications 3-33

4.0 REVIEW OF REGULATIONS PERTAINING TO THE CLOSURE OF NON-CONTAINMENT LANDFILLS IN OTHER JURISDICTIONS . 4-1

4.1 Illinois Environmental Protection Agency 4-2

4.2 Maine Department of Environmental Protection . . 4-4

4.3 Wisconsin Department of Natural Resources 4-10

5.0 DEVELOPING A REGISTRY OF CLOSED SITES 5-1

REFERENCES

1.0 INTRODUCTION

In order to address growing problems and environmental impacts associated with poor operating practices at existing dumpsites in the province, the New Brunswick Department of the Environment has developed and implemented a comprehensive solid waste management program. Under this program, existing disposal sites will be closed and replaced by state-of-the-art disposal facilities, collection networks and recycling programs. Twelve regional waste management systems will take the place of more than 200 dumps that were in existence when the program began. Environmental protection will be incorporated in the design, construction and operation of these new systems. In fact, considerable effort was placed on developing siting as well as design guidelines for sanitary landfills. However, there are concerns regarding the negative impacts the closed, or soon to be closed burning dumps and large municipal disposal sites, could have on the environment.

To address these concerns, the department established closure guidelines in 1987 as the waste management program was being developed. The guidelines were developed to assist dumpsite operators, primarily the New Brunswick Department of Transportation (DOT) and the approximately seventy municipalities, in closing their sites. They were developed in an attempt to minimize the long term environmental impacts of the sites. The guidelines

outline general closing requirements such as fire control, rodent extermination, notification of users and cover requirements. However, as landfilling technology has evolved and more information comes to light, it is apparent that the existing guidelines have become dated. While it is suggested that the existing closure procedures may serve as a general guide, particularly at the smaller rural DOT dumpsites, it was determined that the closure guidelines required revision.

The revision of the guidelines is to be conducted in two phases. The first phase will consist of a literature review of closure regulations and closure activities as well as an examination of mechanisms to develop a registry of closed dumps. The second phase will consist of the development of new guidelines and an examination of land-use issues at closed sites.

This document has been prepared in response to the requirements of the first phase of the revision exercise. It is divided into four sections: a literature review; a review and discussion of guidelines and regulations pertaining to the closure of containment landfills in other jurisdictions; a review of closure methods, procedures and regulations at non-containment landfills (dumps); and identification of options to develop a registry of closed dumpsites.

In the course of the literature review, several key closure issues were identified. First and foremost was the issue of final cover/cap design, and secondly was the issue of leachate and gas management. It was also evident that a distinction between the closure of a containment landfill and a dump was required because of the tremendous difference in the nature of these sites. Proper sanitary landfills have been developed with emphasis on hydrogeological investigations, state-of-the-art design and particular operating practices, whereas dumps were not. In fact, some closure activities at a containment landfill could be considered long-term extensions of certain operating procedures. In particular, leachate collection and treatment, gas collection and groundwater monitoring are typically carried out long after operations cease. Conversely, closure at a non-containment site requires that mechanisms to actually carry out monitoring, such as installation of wells, gas probes, etc. must first be designed and implemented. Closure activities at a dump are often carried out in an attempt to correct the lack of initial engineering and environmental protection at the site. This usually requires remedial type activities as well as monitoring. The issues of capping, gas and leachate management, as well as the need to distinguish between a containment landfill and a dump, were also reflected in the various closure regulations.

In order to conduct a review of closure regulations, each provincial department of environment, as well as Environment

Canada, was contacted. While only Ontario, Alberta and Saskatchewan had legislated regulations, all provinces except Quebec had general guidelines for closure. These guidelines, as well as the regulations, were found to be quite vague and typically required only that a plan for closure be registered with the department and that the site be covered. Closure regulations were also obtained from eight American state environmental or natural resource agencies; Illinois, Kentucky, Maine, Minnesota, New Jersey, New York, Pennsylvania and Wisconsin, as well as the federal Environmental Protection Agency (EPA).

The final section of the report identifies several options for developing a registry or listing of closed sites in the province. Such a listing is suggested in order to make potential land buyers aware if the piece of property they intend to purchase was, at one time, a disposal site. A suggested course of action for the department to follow if a legal registry is to be established is also provided.

2.0 LITERATURE REVIEW OF ISSUES RELATING TO THE CLOSURE OF LANDFILLS

2.1 Scope of the Review

The first task in the study of closure of land disposal sites was to conduct a literature review. The review was conducted in order to identify the environmental implications associated with the closure of sanitary landfills and dumps. The literature review began with an on-line search of the Computerized Engineering Index (COMPENDEX). COMPENDEX is a machine-readable version of the Engineering Index Monthly, which is a monthly compilation of abstracts with an author index and subject index covering literature of engineering and related technical disciplines. Each issue of the index contains indexes and abstracts of over 10,000 articles from some 3,000 titles representing the world's professional periodical, technical report and monograph literature.

Typical examples of journals related to environmental issues in COMPENDEX are: BioCycle, Waste Age, Water Research, Water Pollution Research Journal of Canada, and World Wastes. It also includes proceedings from several conferences such as Air Pollution Control and Symposium on Waste Management. The COMPENDEX database consists of journals, publications and conferences from 1970 to present.

Searches of holdings at University of New Brunswick libraries as well as the New Brunswick Department of the Environment library were conducted. A search was also conducted through the National Technical Information Service (NTIS) bibliographic database. NTIS is the central information source for federally sponsored research in the United States. It also includes information contributed by major corporations, trade associations, universities, private research facilities and several state government sources. The database is updated twice monthly and dates back to 1964. Regulations from a number of jurisdictions in Canada and the US were also reviewed. These will be discussed in a separate section.

2.2 Closure Issues Revealed in the Literature Review

In the course of the literature review, a number of issues relating to the closure of waste disposal sites were identified. In particular, two issues: cap and cover design, and methane gas control, were frequently noted. Leachate control was also noted, although to a lesser degree. Closure and post closure planning, the cost of closure, and land-use restrictions were also discussed in the literature. The following sections are meant to provide the reader with an overview of each of the six closure issues identified above.

2.2.1 Closure and Post Closure Planning

Most waste managers agree that well planned closure and post closure of waste disposal sites is necessary because of the potentially significant impact they can have on the environment and human health. Planning is also necessary because of the costs associated with closing sites in accordance with even stricter regulatory requirements.

In order to develop a closure plan, information must be known on: composition of waste; hydrogeological, geological and soils characteristics; and surface and groundwater quality. At landfills engineered and operated to meet current New Brunswick standards, this information is readily available and can be put to use in order to develop closure plans. However, at older sites, this information is typically unknown and must first be determined before an appropriate and cost-effective closure plan can be developed. The importance of obtaining this background information is critical to the proper design of a pollution control strategy. For example, placement of an extensive cap to limit infiltration and decrease leachate production and contamination may be of little use if the landfill is in direct contact with the groundwater table.

Once a site has been thoroughly characterized closure planning can begin. O'Leary and Tansel (1986) suggest that there

are five critical factors to consider in closure planning: settlement, slope stability, control of leachate and gas, vegetation and final grades.

It should be noted that there were numerous references in the literature regarding the need for well planned closures. This need was further reinforced in that all state regulations reviewed had very extensive closure planning requirements. The specifics of the regulated closure planning requirements will be discussed in Section 3.0.

2.2.2 Leachate Control

Leachate is produced as precipitation and snowmelt percolates through the decomposing garbage in a landfill. Over time the leachate becomes contaminated with a wide range of chemicals which reflect the waste within the landfill. In containment landfills, the control of leachate in relation to closure is not a major concern. This is because the collection system installed at the outset will continue to collect the leachate. However, at those sites where no containment is in place, leachate migration off site may occur. This is of concern because of the impact its release may have on groundwater, private wells, or drinking water supplies.

Leachate migration and contaminant levels are functions of: the thickness and type of the surrounding soils, precipitation, degree of decomposition within the waste cell, distance to the groundwater table and groundwater flow. Therefore, prior to deciding which mechanisms are best suited to control the leachate, the extent of the leachate plume and degree of contamination must be quantified. The hydrogeology of the site must also be completely understood.

The most common method specified to control leachate migration is the placement of an impermeable cap over the decomposing waste. A cap serves to limit infiltration and removes the force (additional precipitation), driving the leachate into the waste and eventually into the groundwater. Capping to control leachate migration is usually considered to be appropriate on smaller sites, where waste is above the groundwater table, and in instances where leachate seeps or down gradient contamination has not been observed. Cover design will be discussed in considerable detail in Section 2.2.4.

In situations where the waste is in contact with the groundwater, active leachate control will be required. Active management requires the placement of extraction wells within or adjacent to the disposal area. Wells placed within the fill are utilized when on-site seeps are evident and the site is in fairly tight soils. Extraction wells may also be placed within the waste

as a means of leachate control when it has been determined that groundwater is percolating upward into the waste deposit (Fanelli, et al., 1990). Active pumping adjacent to the site is carried out as a method of plume management, when the site is located in sands or gravels. Pumping to draw the plume back to the site or to intercept the plume some distance from the site boundary can be utilized. In either case, when leachate or a mixture of groundwater and leachate is actively pumped, arrangements for eventual treatment must be made.

Passive leachate control systems include construction of impermeable barriers around the site and are placed to prevent the lateral movement of leachate or groundwater. Barrier materials include: bentonite slurries, cement grouts and sheet piling. Passive systems are generally employed when the site is situated in confining soils as they must be tied in to an impermeable layer which underlies the waste if they are to be effective. If the vertical barriers are not keyed into an impermeable layer, the leachate will simply migrate under the barrier.

Griffith (1987) reported that installation of bentonite barrier walls were a cost-effective method of preventing off-site migration of leachate. He reported that the types of walls were typically constructed in 900 millimetre widths and could be located on irregular terrain and in a variety of hydrogeological settings (excluding peat and extremely soft soil) to depths over 30 metres.

He also indicated that prior to opting for a soil-bentonite barrier, compatibility testing to determine the impact of the leachate on the wall should be conducted, as some leachates may increase the permeability of the walls.

A similar approach to control leachate migration was also reported by Senger (1990); however, in this instance, a clay barrier and toe drain upslope from the cut-off wall was utilized. Leachate control was required because leachate seeps at the toe of a partially abandoned landfill were noted. The site was underlain by a relatively thin layer of sand and gravel, and under that there was a relatively thick layer of sandy silt and silty clay. The configuration of the underlying soils caused the sand layer to behave as collection system that directed the leachate from the fill to the toe of the slope. Leachate was observed at the surface of the fill area as seeps, and in down gradient wells as the sand layer widened. To control the leachate migration, a compacted clay cut-off wall was placed at the base of the landfill slope to prevent groundwater and leachate from flowing toward nearby developments. In order to prevent the leachate from accumulating, a collection trench was installed at the base of the wall and was connected to two underground storage tanks. As was the case with the bentonite slurry cut-off wall, the clay barrier was keyed into the impermeable layer under the site.

It is important to note that the solutions employed to control leachate migration relied heavily on a complete understanding of the soil conditions at the sites. The cut-off wall would have been completely ineffective if there were no impermeable layer for it to be tied into. Given the cost implications associated with control measures, it is suggested that thorough characterization of the site hydrogeology, leachate quantity and quality as well as an evaluation of potential impacts if migration does occur, is necessary prior to implementing any type of control system.

It is also noted that the cost implications associated with leachate control methods have been considered in the development of state closure regulations. Requirements stipulating that site operators install such systems as part of closure activities are usually not specified in regulations. Rather the need for monitoring is specified and if a significant problem is observed, the type of remediation to be carried out is determined by the operator and regulatory officials on a case-by-case basis. In the three cases noted in the literature, where major engineering activities (excluding cover placement) to control leachate were undertaken, it was noted that they were at sites where an extension of an approval to continue operating, not closure, was being sought.

2.2.3 Control of Methane Gas

2.2.3.1 Methane Gas Generation

As waste in a disposal site decomposes, a variety of gases are generated. Initially, under aerobic conditions, only carbon dioxide (CO_2)is generated. However, as the oxygen is depleted, hydrogen and CO_2 are generated and eventually CO_2 and methane (CH_4), as well as trace amounts of volatilized solvents, are produced. The stage at which CO_2 and CH_4 are produced is commonly referred to as the methanogenic decomposition phase. The production of CO_2 and CH_4 is dependent upon moisture content, pH, temperature, and composition of the waste (Farquhar and Rovers, 1973). Landfill gas is composed of approximately 50% CO_2 and 50% CH_4, although the percentage of CH_4 is usually slightly higher. Production of landfill gases usually begins within two years of refuse placement and continues at an appreciable level for periods of ten to twenty years (Bogardus, 1985 and Ham, 1990).

Formation of landfill gases, particularly methane, require very specific environmental conditions. For example, refuse with moisture contents of 60% - 80% are considered optimum for gas production; however, when excessive infiltration, say after a heavy rain or during the spring thaw, was noted, optimum moisture content was exceeded and gas production levels decreased significantly. Landfills accepting a high percentage of organic

wastes will produce greater amounts of methane than sites accepting insert materials. The type of organic waste also influences methane production. Ham (1990) notes significant increases (20%) in methane, production where the percentage of fats compared to paper in the waste is higher. Waste comprised of sewage sludge or agricultural waste will also produce higher volumes of methane.

Rates of landfill gas production reported in the literature vary widely. This is because of the large number of factors that influence the production of the gas. Ham (1990) reported 6 to 12 litres of gas per kilogram of waste per year (190-400 cubic feet/per ton/per year) are generated in methanogenic decomposition. Bogardus (1985) and Farquhar (1990) reported production rates in the order of 3 to 9 L/kg/year (80 to 280 scf/ton/yr). Bagchi (1990) reported 1 to 8 L/kg/year as typical production rates.

The presence of methane and carbon dioxide within the landfill is not a hazard as oxygen is not present. However, when CH_4 is mixed with oxygen, even at levels as low as 5%, an explosive hazard exists, and is therefore a concern. It also kills vegetation by depleting oxygen levels in the root zone and can cause asphyxiation of animals or humans in confined spaces.

Methane migrates readily through the landfill by diffusion and pressure differentials. Migration also occurs more

readily through sandy soils than through clay, frozen soil or water. Migration distances of 150 metres to 300 metres (Bagchi, 1990 and O'Leary and Tansel, 1986) and greater have been observed. Migration distance depends on atmospheric pressure, presence of a final cover, compaction of the refuse, location of the water table, and soil permeability. Its movement is complex and highly variable.

Given its explosive properties and migration potential, control of methane at waste disposal sites is of considerable importance. Two types of systems to control migration are commonly used: passive vents and active gas pumping systems. The purpose of the systems is to control and direct the methane to the atmosphere to be dissipated or to a burner, rather than letting it move in an uncontrolled fashion where it may accumulate and explode. However, prior to specifying a control method, monitoring should be conducted in order to quantify the problem.

Methane monitoring is carried out by installing special probes in and around the site. Probes are installed in gravel filled boreholes that are sealed near the surface to prevent air infiltration. A single borehole may contain probes at different depths, although it is preferable to have a separate borehole for each probe. Probes are placed to at least the depth of the refuse and should be constructed in such a manner that the pattern of gas migration and its concentration can be determined.

2.2.3.2 Passive Methane Control Systems

Passive systems typically consist of lateral or vertical gravel trenches within the waste or around the site. They are installed in order to provide a convenient passage way for the gas to escape to the atmosphere. In some passive systems, collection pipes are installed in the vertical trenches and the gas is flared by a burner. More elaborate passive systems may also require the installation of impermeable barriers in order to control or redirect the migrating gas toward the vents. Vents within the fill may impinge on the effectiveness of the final cover or vice-versa; therefore, care must be taken in their design and placement. Further, in order for gravel filled or open trenches to be effective, they must be kept clear and free from obstructions, including snow and ice, on a year round basis.

When vents are installed, it is recommended that they penetrate either to an impermeable layer below the fill (clay or the water table) or extend 1.5 to 2 times the depth of the landfill in order to be effective (Farquhar, 1990). Bagchi (1990) recommends a minimum of one vertical type vent per 7,500 m^3 of refuse as typical for a passive methane gas control system.

Passive venting systems are applicable to small, shallow, remote and very old sites (Farquhar, 1990). Bagchi suggests they are acceptable at sites 40,000 cubic metres or less in size. By

way of contrast, Farquhar recommends that active systems should be employed at site sizes in the order of 10,000 cubic metres.

2.2.3.3 Active Methane Control Systems

An active gas extraction system is comprised of a network of vertical gravel filled boreholes fitted with collection pipes connected to headers. The headers feed to a pump which 'vacuums' the gas out of the landfill and directs it to a flare. As with the passive system, the extraction wells may be installed within the waste or around the perimeter of the fill area.

Boreholes for the extraction wells range between 300 and 900 millimetres (mm) in diameter and the collection pipe is typically perforated PVC, 150 to 200 mm in diameter (Bagchi, 1990; O'Leary and Tansel, 1986). The depth of the borehole may range from 50% to 90% of the depth of refuse to the water table. Proper spacing of the extraction wells is the key to effective and efficient gas removal. As is the case when groundwater is pumped, gas extraction wells have draw down zones or zones of influence. To achieve optimum extraction rates, the zones of influence should overlap.

The header pipes connecting the collection pipes in the extraction network are constructed of non-perforated plastic pipe, 150 to 200 mm in diameter. Header pipes that underlie the final

cover require constant maintenance in the first few years. This is because of excessive and differential settlement which damages the line. Active systems are recommended by Farquhar when a site is less than 20 years old, is greater than nine metres in depth, is situated within 400 metres of a developed area and is greater than 5,000 tonnes (~10,000 m^3) in size.

2.2.4 Final Cover and Cap Design

2.2.4.1 Role of Covers in Landfill Closures

Covers are multi-layer (two to several), multi-media structures which are placed over waste disposal sites, in order to prevent precipitation or surface run-on from infiltrating into the fill area. In Ontario, however, the purpose of a landfill cover, as set out in background policy statements prepared by the Ministry of Environment, is not to restrict infiltration into the waste but rather to promote controlled infiltration in order to increase waste decomposition and promote the rapid stabilization of the fill. The following will discuss cover/capping of landfills in terms of their more common function, limiting infiltration of precipitation into the waste.

The placement of a final cover is often cited as one of the most important activities undertaken in closure. Further, it

is often the only activity routinely required by regulatory agencies, particularly in Canada as disposal sites are closed. In addition to its primary purpose, stated above, covers also serve to: prevent animal or human contact with the waste, minimize post closure production of leachate, minimize post closure maintenance and improve aesthetics and site reclamation possibilities (Hatheway and McAney, 1987). These functions are achieved through design features which consider: wind and water erosion, run-off and run-on, vegetation, slope stability, settlement, freeze and thaw cycles, impacts of plants and animals, containment of gases and infiltration. Typically limiting infiltration is the key design parameters and the other aspects of cover design are established to enhance, improve or support this element.

2.2.4.2 Factors Considered in Cover Design

The following discussion presents the issues to be considered in cover design. It also illustrates the strong relationship between the various design features used to achieve the objective of minimization of infiltration.

Infiltration

Limiting the infiltration of liquids through the final cover is the primary objective in cover design. Infiltration may be limited by a combination of techniques and design considerations. Grading the cover to promote run-off and utilizing impermeable materials to prevent downward migration serves to effectively decrease infiltration.

Infiltration may also be limited by the placement of a drainage layer between the vegetative and impermeable layers. This layer is meant to carry any infiltrate that passes through the vegetative layer before a head can build up on the barrier layer. Infiltration is also limited by the placement of a vegetative layer. This layer, which is the uppermost surface of the cover, promotes evapotranspiration, stabilizes the slopes and helps protect underlying layers from wind and water erosion.

Wind and Water Erosion/Slope Stability

Control of wind and water erosion is important to the long term stability of cap slopes, maintenance of run-off control measures and the integrity of the cover. Wind and water erosion are controlled primarily by the presence of a vegetative cover. Water erosion is also controlled by the placement of hydraulic

breaks across long slopes and by gentle grading at the site rather than using steep slopes. Similarly, slope stability is enhanced by the placement of vegetative cover and gentle grading.

Vegetation

Vegetative cover serves many functions in final cover systems. It resists erosion and decreases infiltration by evapotranspiration and it allows steeper slopes to be placed (i.e.: improved stability) which promotes run-off. Vegetation may also prevent soils from drying out and cracking, thereby changing their characteristics as a moisture barrier.

Landfill Gases

As discussed in Section 2.2.3, control of methane gas is an important consideration in closure because of its hazard and migratory potential. Control of methane gas when a cover is placed is of concern as installation of an impermeable layer over the waste promotes lateral migration. An effective cover design should incorporate a gas venting layer above the last lift of waste and below the impermeable barrier.

Settlement

While virtually nothing can be done to prevent the settlement of decomposing waste, its impact on the design of final covers must be considered. This is because settlement, particularly differential settlement, will cause the cover or upper protective cover layers to crack, thereby providing open channels for precipitation or surface run-on to flow into the waste and channels for landfill gases to escape.

O'Leary and Tansel (1986) state that 90% of settlement will occur in the first five years and the balance of settlement may take place over the next 25 years. Hatheway and McAney (1987) state that settlement of 25% to 50% of the landfills depth is not unlikely. Rapid and higher settlement rates occur at sites with a high component of organic wastes, high moisture contents and poor (low), in-place, compaction densities. Unfortunately, settlement is not uniform and it cannot be predicted; therefore, final cover systems must be routinely monitored and maintained.

In terms of cover design considerations, it has been suggested that rigid covers such as asphalt or concrete should be avoided because when subjected to even minimal settlement, they will crack. It is also suggested that thicker soil covers are desirable. This is because they will likely result in an improved growing medium for the vegetative cover and they facilitate

maintenance. For example, if a crack is noted in the upper layer, the extra soil can be easily redistributed without major equipment or construction activities. Settlement in relation to other cover design factors should also be considered in terms of ease of repair. A cover that includes a number of layers, constructed out of a variety of materials, may be technically difficult as well as expensive to repair.

Freeze and Thaw

Like settlement, freezing and thawing is beyond the control of a landfill operator or designer; however, measures to protect various elements of the cover susceptible to freezing can be incorporated into the design of the cover. Gas control systems placed within the cover system as well as the impermeable layers should be protected from freezing and thawing if they are expected to operate properly. Freeze/thaw cycles may cause breaks in header lines between gas extraction wells or they may cause a clay or synthetic layer to crack. In order to decrease the impact of freezing/thawing, thicker vegetative layers, extending below the frost line, are often specified.

Root and Animal Penetration

Design of a final cover system should also incorporate measures to protect the impermeable layers, from plant roots or burrowing animals. Both roots and animals may penetrate the upper vegetative layers which protect underlying layers. Measures to control these impacts include frequent maintenance of the vegetative layer (repairs to gullies) and use of rodenticide. Mowing of the cover is not encouraged as it reduces the amount of above-ground plant material which carries out transpiration. A more permanent and expensive method to protect the impermeable layer is to place a biotic barrier under the vegetative layer and above the impermeable layer. Biotic barriers typically consist of cobble, rip rap or even construction rubble.

As stated at the outset, each of these aspects must be considered in light of overall design objectives. Trade-offs among the various factors must also be considered. This is because some elements of a design are contrary to the role of other elements. For example, a design to promote run-off must be tempered by the need to prevent erosion.

2.2.4.3 Structural Components of a Cover

Most final covers consist of a minimum of two layers, an impermeable or hydraulic barrier placed above the waste and a protective or vegetative layer placed above the barrier. Some cover systems consist of a number of layers. The following describes the various layers used in cover systems and their associated functions. Final cover designs, as specified by a number of jurisdictions, are presented in Section 3.2.5.

Hydraulic Barrier

The hydraulic barrier is an impermeable layer that is placed above the waste to prevent inflow of liquid. It is placed below a layer of topsoil which protects it and supports vegetation. The hydraulic barrier is typically constructed from recompacted clay or bentonite, or from a synthetic geomembrane. Soil thickness is typically 300 to 600 millimetres with permeabilities ranging between 1×10^{-6} to 1×10^{-8} cm/s. The most effective barriers are achieved when proper equipment, such as sheep's foot rollers, is used to place the clay. Thicker layers are less susceptible to damage caused by differential settlement and are therefore preferable.

Geomembranes may also serve as a hydraulic barrier, because of their extremely low permeabilities, i.e.: in the order of 1×10^{-12} cm/s. The recommended minimum acceptable thickness is 1 mm or 40 mil, however 1.5 to 2.0 mm (60-80 mil) is preferred.

Hydraulic barriers are susceptible to two principle failure mechanisms: chemical and mechanical. Chemical vapours from landfill gases or leachate, should it seep to the elevation of the cover, may breech the cover by decreasing its permeability by causing cracks or holes.

Mechanically, failure may be related to construction activities or environmental conditions. Liners may be damaged by construction or heavy equipment travelling over an insufficiently thick protective layer; differential settlement; tensile stresses generated by the weight of the upper layers of the cover and degree of slope; and punctures from materials in the landfill that protrude out of the waste deposit. Geosynthetic liners are more susceptible to rips, tears and punctures than soil barriers.

Environmental conditions such as continuous freeze/thaw cycles, wetting and drying, root penetration and burrowing animals can cause covers to fail. Each compromises the hydraulic barrier by creating cracks or holes in the surface. Both soil and geomembranes are susceptible to environmental failures.

Vegetative Layer

To protect the hydraulic barrier from chemical and mechanical failures, a vegetative or protective layer is usually required as part of a cover system. This layer is usually comprised of two layers, a lower layer and a topsoil or organic layer. The lower layer, which is next to the hydraulic barrier, should be resistant to rain impact and run-off as well as being stable. It should be between 0.3 and 1.05 metres in thickness in order to protect against frost penetration. The organic layer, which is above this, should be comprised of topsoil that can sustain vegetation. Typically depths of 100 to 150 mm are required.

Selection and maintenance of the vegetation on the cover is an important design consideration. Grasses and shrubs may be sown on the vegetative cover. Placing plants with deep or intolerant root systems may impinge on the cover's effectiveness and must therefore be selected carefully.

Foundation Layer

A foundation, grading or gas control layer is placed over the last lift of waste in order to protect the underside of the cap from the waste. This layer also provides load bearing support for

the upper layers of the cover above, and allows it to be placed on a prepared surface of a desired grade. This layer can also accommodate the gas venting system, which is an important element of closure. Material typically specified for this layer is coarse gravel soil, 150 to 600 mm in thickness.

Biotic Barrier

Biotic barriers, as discussed previously, are placed between the vegetative layer and hydraulic layer and are meant to impede burrowing animals and penetrating roots. This layer is most commonly omitted in cover design.

Drainage Layer

The function of a drainage layer is to intercept any precipitation that flows through the vegetative layer and divert it away from the hydraulic barrier. The effect this layer creates is often referred to as the "wick effect" and its need is often a source of controversy. As evidenced in the various regulations, some jurisdictions feel the layer performs a valuable function and is worth the additional cost and have specified its use while others have not.

The drainage layer is placed between the vegetative layer and the hydraulic barrier. It should consist of clean, high permeability gravel, 150 to 300 mm in thickness. It should slope toward collection points around the site. In place of a gravelly layer, geonets or geogrids may also be used.

Filter Layers

Filter layers are utilized between the layers of a cover system where coarser soils are placed below finer materials. This is because of the potential for the finer particles to move downward into the coarser material with infiltrate and eventually clog the open-pore network of the coarse layer. Filters are often located between the vegetative layer and the underlying drainage layer, or between the hydraulic barrier and the foundation layer. In both cases the filter serves to protect the coarse grained layers from becoming clogged with finer particles from the layer above.

Covers are a critical aspect of virtually all closure operations. These various layers of a cover, as discussed above, function together in order to minimize the infiltration of liquid into the waste. To assist designers, cover designs can be evaluated by using a commonly available computer simulation model (the Hydraulic Evaluation of Landfill Performance (HELP) Model).

This model takes into account local precipitation as well as the characteristics of various layers in the cover, including vegetation, soil permeabilities and absorption capacity.

2.2.5 Cost of Closure

In the past, requirements for the closure of landfills were not extensive and correspondingly, closure costs were not high. However, as landfilling regulations have become more stringent, planned and engineered closures are now routinely required. Closure typically requires: grading, landscaping, run-off controls and placement of final caps. In addition, lengthy post closure monitoring and maintenance periods (20 to 30 years) are also commonly required. During post closure, extensive groundwater sampling programs, as well as leachate and methane monitoring and control programs are conducted. As both closure and post closure requirements have increased, so have costs.

Glebs (1988) estimated that, in 1975, closure and post closure costs were an insignificant component of a typical landfill's life cycle costs, but by 1990 would likely amount to nearly 15% of the overall life cycle cost. Because of the dramatic cost increases, particularly in the last five to ten years, most site operators now plan to recover projected closure costs through tipping fees. This ensures the funds will be available when the

site closes. Given their significance, the following sections provide a description and order of magnitude estimate of closure and post closure costs.

2.2.5.1 Closure Costs

Glebs (1988) and Glebs and Jusczyk (1990) reported typical closure costs for a sanitary landfill to be in the order of $37,000 (Cdn) per hectare ($13,000 (US) per acre). In this example, the cost of closure included: materials and placement of a two-foot clay cover and six inches of topsoil, seeding, soil testing, a passive gas venting system, wells to monitor leachate head build-up on the liner, and administration. It was also projected that, as legislation becomes more stringent, closure costs could be expected to increase to between $71,000 and $142,000 (Cdn) per hectare ($25,000 to $50,000 (US) per acre).

By way of comparison, cost estimates prepared by the Maine Department of Environmental Protection (DEP) for the closure of non-engineered sites were noted to range between $204,000 and $369,000 (Cdn) per hectare ($72,000 to $130,000 (US) per acre). The variation in the DEP estimates can be accounted for by varying cover requirements.

The lower cost estimate reflects minimum cover requirements and the highest price reflects maximum cover requirements (see Table 2-2). It is suggested that the estimates prepared by the Maine DEP, which are considerably higher than those prepared by Glebs, reflect the extra effort required to properly close a dump as opposed to the effort required in closing a landfill. The difference is also due to more stringent cover requirements and considerably higher unit costs (two to seven times) for seed, topsoil and clay. In preparing closure estimates, unit prices, detailed in Table 2-1, were used. It should be noted that they do not include the cost of: cover materials, hydrogeological assessments, groundwater monitoring, or leachate treatment.

The cover specifications and associated cost estimates presented in Table 2-2 reflect three levels of protection suggested by the Maine Department of Environmental Protection. Cap requirements typically vary as the site's proximity to sensitive resources varies.

TABLE 2-1

Estimated Closure Costs*

TASK	PER ACRE COST/$
Grading	750
Gas Control	3,000
Seed and mulch	14,500
Drainage control	3,000
Rat extermination	750
Culverts	500
Cover testing	1,000
Engineering and design	7,500
Construction	10,000
TOTAL	$41,000

* Pers Comm, Robert Birk, Maine Department of Environmental Protection

TABLE 2-2

Cap Specifications* and Unit Costs**

1. Clay Cover

Material	Unit Cost	Cost per Acre
6" topsoil	$15/cy	$12,000
15" clay	$5-15/cy	$12,100-$36,300
6" sand	$8/cy	$6,500
		$30,600-$54,800

2. Restrictive Cover

Material	Unit Cost	Cost per Acre
3" topsoil	$15/cy	$ 6,000
9" borrow	$6/cy	$ 7,200
12" sand	$8/cy	$12,900
filter	$1/sy	$ 4,800
40 mil PVC	$4/sy	$19,600
12" clay	$10/cy	$16,100
6" sand	$8/cy	$ 6,500
		$73,100

3. Secure Cover

	Cost per Acre
Same as the cover specified above except 24" of clay is required	$89,200

* Cap specifications are described from the uppermost layer down toward the waste.

** Pers Comm, Robert Birk, Maine Department of Environmental Protection

2.2.5.2 Post Closure Costs

As indicated, post closure consists primarily of monitoring and maintaining the site over an extended period of time to ensure the environment and public health and safety is protected. Typical post closure activities include annual inspections, site surveys, groundwater, methane gas and leachate monitoring, maintenance and repair of the cover, cleaning of leachate collection lines, leachate treatment, operation of gas collection systems, and reporting. Post closure activities and costs vary from site to site depending upon the extent of the monitoring network, the general condition of the site at the time of closure, and whether or not the site was an engineered site. For example, the monitoring system at an engineered landfill, where leachate and methane were collected and disposed of, would be different than one at a non-engineered site. Similarly the approach to controlling leachate or methane gas at an engineered site would be different than the approach at a non-engineered site.

Glebs and Jusczyk (1990) reported typical post closure costs for an engineered (containment) landfill. These costs are presented in Table 2-3.

It is estimated that comprehensive post closure maintenance at larger landfills may cost in the order of $180,000 per year or more than $5.5 million over a 30-year post closure care

period. The actual cost of closure will be directly related to the regulatory requirements (frequency of sampling, number of parameters and points, length of monitoring period) and the cost of services (laboratory analysis, leachate treatment, transportation, labour, utilities, etc.) in the particular jurisdiction where the site is located.

TABLE 2-3

Long Term Closure Costs

ACTIVITY	COST*
Site Inspections	$70-$230/inspection
Monitoring	
Groundwater	$1,150-5,750/well/year
Surface water	$170-230/point/year
Leachate	$1,150-11,500/year
Gas	$10-20/point/year
Control	
Transportation of leachate	$3-15/cubic metre
Treatment of leachate	$1-30/cubic metre
Gas system operation (active)	$11,500-34,500/year
Electricity	$575-11,150/year
Maintenance	
Leachate collection system cleaning	$1.13-1.90/metre/year
Lift station	$1,150-2,300/year
Landscaping and cover maintenance	$140-280/hectare/year
Gas and leachate extraction systems	$1,150-5,750/year

* Cdn dollars

2.2.6 Land-Use Restrictions

2.2.6.1 Conventional Land-Use

There are a number of potential uses for a closed landfill. Common end-uses have included the development of recreational facilities, ski hills, golf courses and parks. Less common uses have included the development of dog tracks, malls and buildings (i.e. the John F. Kennedy Presidential Library in Boston and Mile High Stadium in Denver).

It has been argued that the final use of a closed landfill is a direct function of the cost of developing alternative lands. However, it is also suggested that environmental and engineering considerations must also be considered in land-use planning. Final use of a closed landfill will depend on a variety of factors, such as:

ECONOMIC

- surrounding land-use pattern
- proximity to developed areas
- cost of land
- cost of reclamation

ENVIRONMENTAL

- general condition of the site
- gas production expected

- settlement
- compatibility with and impact on closure system

ENGINEERING

- degree of closure planning undertaken during operational phase

The relationship between these factors may be demonstrated by considering two closed sites both undergoing settlement and both generating methane gas. One site is located in the heart of a rapidly growing commercial/industrial area and the other is somewhat isolated. In this instance, both sites would require certain engineering activities be undertaken to return the site to some use. However, the degree of engineering (and cost) will be a function of the proposed use and the end use will be a function of site location.

A more centralized site offers more development potential because of its location; however, the same site will also require substantially more engineering to support this type of use. For example, because of the impact settlement could have on an overlying structure, its control must be addressed at the outset by either consolidating the waste by pounding the surface with heavy weights (8 to 20 ton weights from 30 metres, 3 to 15 times), specialized design, founding the building on underlying bedrock or excavation of the waste. Each of these options has limitations and

is usually expensive. Surface pounding may be less expensive than placing piles to bedrock, but it can only accommodate a building that is two stories high and settlement will still occur. Gas problems will also have to be addressed. In this case, active collection and flaring and comprehensive monitoring would be required to ensure the safety of the building's occupants.

At an isolated site, passive uses such as recreational areas, ball diamonds, trails, picnic areas and golf courses may be more appropriate. Accordingly, the engineering necessary to accommodate the use will be less extensive, and will cost less. In order to deal with gas or settlement problems where the land-use is less intense, passive gas venting and a good monitoring and maintenance program may suffice.

When considering end-uses, the planners must compare the lower purchase price of a closed landfill site to the cost of surrounding lots and the higher cost of construction and maintenance required to "recover" a closed site. Such was the case with the JFK Library noted earlier. Typically, a lot near Boston proper, on the harbour, and in an aesthetically pleasing location, would be relatively expensive; however, since that same lot was once a landfill, the land costs were considerably lower. Therefore, cost savings in land purchase could be used to finance the special construction techniques to build on a closed landfill.

On more modern landfills, where covers and caps have been installed, potential land-uses become somewhat limited. This is primarily because most activities would compromise the cover. Some activities, such as construction involving the placement of piles on bedrock, would also compromise the underlying lining and leachate collection system. Final land-use is often specified by regulatory authorities. The permitted uses range from virtually nothing (Maine) to construction of buildings (Illinois), but in all cases the regulations stipulate that the use is not to compromise any aspect of the closure system.

2.2.6.2 Landfill Reclamation

In addition to the conventional post closure land-use considerations identified above, a number of jurisdictions have reclaimed the land at a closed site by "mining" the waste within a landfill.

Spencer (1990) reported that landfill mining pilot projects were being carried out at sites in New York, Connecticut, Delaware, Florida and Massachusetts. The purpose of these projects has been to recover recyclables and cover material (from the decomposed waste and soil used as daily cover) and to use the space created by the excavation for the deposition of more waste. In some instances, mining serves to down-size and stabilize the area that is to be closed using conventional methods.

Reclamation is carried out by using equipment commonly used in the mining industry. An excavating machine placed at the toe of the landfill directs the waste to a conveyor and vibrating screen. Here, the waste is divided into an oversize stream (depending on mesh size) and recoverables. The recoverable stream is further processing into 'dirt' and recyclables.

Prior to embarking on a mining project, the following factors should be considered:

- availability of landfill space
- cost of disposal
- energy value of reclaimed waste
- markets and revenues for recyclables extracted
- cost of landfill cover
- cost of conducting the "mining" operation
- cost of disposing of hazardous waste if uncovered in the excavation

An extensive and expensive mining operation in an area where the cost of disposal is relatively low and the market for recyclables is weak, may not be economically feasible. Further, experience from previous mining projects suggests that: site sampling be conducted to minimize the possible excavation of hazardous waste, that methane levels be monitored throughout the operation to protect on-site workers, and that recovered material to be used as daily cover or as fill material be tested to ensure

it is not heavily contaminated. Planners also suggest that future or long term feasibility of this approach will require existing operations (dry tomb sites) shift toward practices that encourage destabilization, such as leachate recirculation. The impact of changing operating practices is now being studied in Delaware. Over a five-year study period, two one-acre lined cells, one dry, one recirculating leachating will be monitored and waste degradation, gas production and leachate generation rates compared. If the waste in the 'wet' cell has decomposed, gas production has increased and volume of or contamination level of leachate has decreased; the waste management authority will consider reclaiming the site and processing the stabilized waste to recover recyclables and soil.

3.0 REVIEW OF SANITARY LANDFILL CLOSURE REGULATIONS IN OTHER JURISDICTIONS

The purpose of this section is to provide a summary of guidelines and regulations with respect to the closure of sanitary landfills. The summaries are based on a review of regulations provided to the study team and discussions with officials from selected regulatory agencies. Regulations were obtained from eight American state agencies and the federal EPA; and one Canadian provincial agency. Guidelines for closure procedures, from the other provinces as well as Environment Canada, which were far less detailed than the regulations, were also reviewed.

In the review of the regulations it was determined that the key elements of closure typically include information relating to: the length of the post closure period, closure planning requirements, financial assurance and closure cost estimates, gas and leachate management, cover and slope stabilization, groundwater monitoring and land-use restrictions. It was also determined that although the key elements of closure listed above were important, most attention, as in the literature review, was focused upon final cap requirements. It was found that most regulatory agencies had very specific requirements for cover and typically specified, in detail, cover design criteria. Therefore, in addition to the summary of regulations, a review of various cover/cap design specifications will also be presented.

In the review of the regulations, it was found that most closure regulations are performance based rather than design specific. For example, regulations usually stipulate that operators are required to close sites in such a manner that minimizes the release or impact of leachate or landfill gases and protects human health and the environment. How this is achieved is left to the discretion, imagination and experience of the operator and regulatory agency. It is understood that specifying the number of groundwater wells to be monitored, parameters to be measured, and frequency of sampling is best left as a performance standard given the wide variation in sites, sizes, and locations. However, some aspects of closure are easily specified, these include cover and caps, vegetative covers and slopes. Requirements for reporting, financial assurance, minimum monitoring periods, and land-use restrictions are also often specified.

Furthermore, it is important to recognize that these regulations have been struck to deal with the closure of a sanitary landfill. As noted in the introduction, there is a considerable difference when planning and carrying out the closure of a non-engineered facility as opposed to a sanitary landfill and these are reflected in the regulations.

3.1 Elements of Closure Regulations

The issues most commonly addressed in closure regulations include: length of post closure, planning, financial assurance and cost estimating, gas and leachate management, cover and slope stabilization, groundwater monitoring and land-use restrictions. As the regulations will be discussed in the context of these terms, the following descriptions or definitions are presented, then the specifics of several of the regulations will be discussed.

Closure refers to the various activities undertaken at a waste disposal site that is no longer active in order to minimize the impact of the site on the surrounding environment. Closure activities may range from minimal, simply abandoning the site and barring further use, to significant where perimeter toe drains to intercept leachate are installed, full scale groundwater monitoring is conducted and a clay cap is placed.

Post closure period is the length of time monitoring activities must be carried out at a closed site. It also defines the period for which monies to sample, analyze, monitor, survey, upgrade and generally care for the site must be available and disbursed. The post closure period usually begins when actual closure activities are complete and a certificate of closure has been issued and continues until the site has stabilized, which is usually a regulated minimum of 20 to 30 years. Stabilization typically means no further settlement of the site is observed, gas

and leachate production have subsided and results of groundwater monitoring are statistically constant.

Closure planning refers to the detailed plans, drawings, and specifications that are submitted to regulatory officials outlining what specific activities will be undertaken in closure and post closure plans must include such things as: monitoring schedules, parameters to be analyzed, how closure will be conducted, controlled and financed. Closure plans for existing sites are usually required at least one year prior to the start of closure activities to allow officials to review and evaluate the plan. Closure plans for new containment landfills are usually required as part of the initial permitting process.

Financial assurance refers to the way in which the landfill owner plans to finance both closure and post closure monitoring activities, after the site has stopped generating revenues. Financial assurance requirements in existing regulations are very specific and details with respect to assurance were routinely required as part of the initial permitting process. The regulations require lengthy closure cost estimates and frequent revisions, and minimum contributions and procedures for disbursement are often stipulated. Typical methods of financial assurance include: bonds, insurance agreements, trust funds, escrow accounts or letters of credit.

Gas and leachate management refers to the methods for handling and disposing of the gas and leachate generated during the post closure period of the landfill. At state-of-the-art containment landfills, management of gas and leachate is typically an extension of operating activities. For example, leachate directed to a local sewage treatment plant (STP) will likely continue to be directed to that plant until monitoring indicates that the quality of the leachate is such that it can be discharged to a receiving stream without adverse impact. Active management of both gas and leachate is required by most closure regulations related to new sites because of the significant impacts uncontrolled or unmonitored release can have on public health, public safety and the environment.

Cover and slope stabilization refers to the materials and methods used to limit infiltration of precipitation into the waste. Materials for capping the site, their thickness and permeability, are usually specified in closure regulations. Most covers or caps are required to be a minimum of 300 millimetres (12 inches) in thickness and to be re-compacted to a permeability of 1×10^{-7} centimetres per second. Many jurisdictions specify additional requirements; ie.: composite liners, or additional layers, or alternatives, but virtually no jurisdiction requires less.

Slope stabilization is usually specified in closure regulations, and includes such things as minimum and maximum grades, erosion control methods, measures to limit run-on and

promote run-off, vegetation and protection of the impermeable (cap) layer.

Groundwater monitoring refers to the activities undertaken to determine if the landfill has contaminated the groundwater in the vicinity of the disposal area, at the property boundary and down gradient from the site. As with gas and leachate management, groundwater monitoring is often an extension of activities carried out during the operating life. Monitoring may vary or decrease with age and as contaminants and containment levels change.

Well construction specifications, parameters to be monitored, and methods of statistically analyzing results are usually set out in closure regulations.

Land-use restrictions stipulate acceptable activities on closed disposal sites. Restrictions vary considerably. Some jurisdictions will not allow any use of the site, whereas some will permit considerable development. However, in all cases, any activity that compromises the cover or any ongoing monitoring or closure management activity is not permitted. Some jurisdictions are better equipped to deal with enforcing restrictions as they have mechanisms to identify closed sites such as notes to deeds of title.

3.2 Regulations for the Closure of Sanitary Landfills

The following summarizes closure regulations from several American jurisdictions, and provides a summary of regulations and guidelines in Canada. While more than 40 states have regulations relating to closure, Illinois, Maine and New York are presented in detail in the following sections. They were selected because they are comprehensive, they specify different methods to achieve similar goals and they consider environmental protection in light of cold climates.

In the review of closure requirements, it became clear that neither regulations, guidelines or policies in Canada have evolved to the level of their American contemporaries. This is suggested for two reasons, the need for regulations and control in the United States is greater and is perceived to be greater, and historically the Americans have relied heavily on regulation to achieve their desired objective.

3.2.1 Illinois Environmental Protection Agency

The state of Illinois has recently revised their nearly 20 year old regulations respecting waste management, to reflect new waste management methods and practices, and minimum criteria established by the US Environmental Protection Agency. These comprehensive regulations, which came into effect on

August 7, 1990, include such things as: siting and design standards, operating and groundwater monitoring requirements, closure specifications, permitting rules and financial assurance requirements. Closure regulations, which are a combination of performance and design standards, at new disposal facilities are described in the following paragraphs:

Closure Planning Requirements

Section 811.770, 812.114, 812.313

When an operator applies for a permit to develop and operate a landfill, he is also required to prepare a written closure plan that describes all actions that will be carried out to close the facility, provide care during the post closure period and includes an estimate of the cost of closure and long term monitoring in accordance with the regulations. The plan requires a considerable amount of detail such as: contour maps, closure steps, methodology for decontamination of equipment, cover specifications, placement techniques, cost estimates and a quality assurance program.

At the time of closure, the operator and engineer must submit documentation of the closure procedures. Once this is received, the Agency will issue a closure certificate and specify the beginning of the post closure period. At the end of the post closure period, the operator and an engineer must submit a report

documenting that the facility does not constitute a threat of pollution.

Post Closure Period

Section 811.303, 813.401, 402, 403

Generally, the post closure period extends 30 years beyond the operating period of the facility. However, where steps such as shredding or leachate recycle are taken to stabilize (biodegration and settlement) the waste, the post closure period extends for 20 years beyond the operational phase.

During the post closure period the operator is required to submit reports to the Illinois Environmental Protection Agency on an annual basis. This report must contain monitoring data from leachate collection, groundwater monitoring networks, gas collection as well as statistical summaries of the data, discussions of the information and changes, if any, to the monitoring program.

Financial Assurance and Closure Cost Estimates

Section 811.700, 704

The regulation requires the facility operators to prepare a written estimate of the cost of closing the facility and carrying out post closure monitoring and maintenance as part of the initial permitting process. This includes estimates for the analysis of groundwater samples, the installation of a cover, erosion control measures, mowing the vegetative cover on the cap, and alternatives for management of landfill gases. The regulation requires the operator to review, and, if necessary, revise the cost estimates each time the permit is renewed (a maximum of five years) or when facility modifications may affect closure costs. The regulation also requires that financial assurance for the cost of closure and post care is provided. It is quite specific as to the type of assurance that is acceptable, including the establishment of a trust fund and associated requirements of each assurance method.

Leachate Management

Section 811.309 g)(1) and (2)

Leachate collection and treatment, whether on-site or off, is required for a minimum period of five years after closure. The collection and treatment period may exceed five years if leachate strengths exceeds state standards for direct discharge.

Gas Management

Section 811.310 b)(7), c)(1)-(4) and d)(1)-(3)

Generally, gas monitoring on a monthly basis is required at containment landfills during its operating life and a minimum of five years after closure. Quarterly monitoring is required for a minimum of 15 years after closure. However, if concentrations decrease and low levels are sustained, monitoring frequency decreases. If monitoring reveals that allowable methane concentrations (50% of the lower explosive limit) are exceeded, then an active gas management system must be installed. Interestingly, gas collection is also required during operation and post closusure, if leachate is recirculated as part of that management system. In both monitoring and gas collection, there are specific provisions to ensure that the cover system will not be compromised.

Cover and Slope Stabilization

Section 811.110, 811.111, 811.314 and 811.322 a) through c)

Construction of the landfill cover is a specific design standard whereas slopes, stabilization and final configuration of the site is performance based. Placement of a low permeability cover is required no later than 60 days after the last lift of waste is deposited.

The cover is specified as requiring three feet of soil compacted to achieve a permeability of 1 x 10^{-7} centimetres per second (cm/s), or a geomembrane or other material that can meet the performance standard achieved by 3 feet of 1 x 10^{-7} cm/s material. The cover must also tie into the liner system.

The regulation also requires that a layer to protect the low permeability layer be installed. This layer must be a minimum of three feet. This thickness is specified in order to provide support for vegetation, its protection from landfill gases, freezing and root penetration. Monitoring of the cover and its vegetation is required quarterly for five years after closure and less frequently for an additional period of 15 years.

Installation of a drainage layer between the low permeability layer and the protective layer to control infiltrate was contemplated. It was agreed that the layer improved the performance of the cover marginally, but raised the costs significantly. Therefore, it was not specified in the final regulation.

With respect to slopes and contouring at the site, several requirements should be noted. During closure operations and post closure, drainage ways must be able to accommodate run-off from a 100-year, 24 hour storm event without erosion. Final slopes are required to blend in with the surrounding topography and drain run-off away from the cover.

Groundwater Monitoring

Section 811.319

Extensive groundwater monitoring is required as part of site operating procedures and is required on a quarterly basis for a minimum of 15 years after the site is closed. However, at a point either five years after the closure providing a threat of groundwater contamination has been eliminated or 15 years after closure, monitoring frequency may decrease to an annual basis on a well by well basis. Monitoring during closure is very much an extension of the comprehensive groundwater analysis and assessment required in site selection and operation, therefore readers are referred to the actual regulations for complete and accurate description of the specific requirements.

Land-Use Restrictions

Section 811.322 (d)

Construction of any structure over a closed site is permitted provided that it is compatible with land-use in the area and does not interfere with leachate collection, gas management or monitoring. While this infers that buildings could be situated on top of closed sites, state officials indicated that recreational usages (golf courses, etc.) are more typical.

3.2.2 Maine Department of Environmental Protection

Maine revised their solid waste regulations in May, 1989 to reflect advances in landfilling technology and because of public pressure to implement more stringent regulations. The new regulations pertaining to closure are a combination of performance and design standards, but the performance standards were noted to be quite vague and left much to the discretion of the department. The key components of the closure regulations are described in the following paragraphs:

Closure Planning Requirements

Section 401.7(A) 1 through 16

A comprehensive closure plan is required by the department one year before closure begins, or if the site operator applies to establish another disposal facility or treatment system (whichever is first). The plan requires information regarding: schedules for public notification of closure, rat extermination, fire control, grading, slopes and placement of final cover, location and method of retrieving cover material, drainage controls, groundwater flows, leachate and gas monitoring, detection and control procedures, proposed closure designs, cost estimates, quality control and quality assurance, proposed final use and a post closure and maintenance program.

The closure design must be based upon information determined in a site specific geological investigation, the degree of contamination at the site, and the geographic location of the site. The design plans submitted to the department must show final elevations, slopes, site topography, all structures, monitoring points and surface water sampling points.

Post Closure Period

Section 401.8

Facility operators are required to submit a post closure proposal to the department outlining how monitoring and maintenance will be conducted, how much it will cost and how it will be financed over the 30 year post closure period. During the post period, monitoring of: groundwater, surface water, gas, leachate and the leak detection system is required. Monitoring is required quarterly or until the department approves a decrease in frequency or parameters or does not require further monitoring. Monitoring of the leachate collection and treatment system is also required and the frequency is determined by the department on a case-by-case basis. In addition to the monitoring, maintenance of the cover, drainage system and site security (prevention of dumping of waste after closure) is required during the post closure period.

Financial Assurance and Closure Cost Estimates

Section 400.10, 401.7(14), 401.8(B) 2 and 3

The closure regulations require that a cost estimate of closure and post closure activities be prepared. Further, once the estimate has been made, all site operators, except municipalities or groups of municipalities, are required to establish an escrow account to finance the closure of the disposal facility.

To ensure that sufficient funds will be available in escrow to conduct the site closure, money must be available to: hire a third party to conduct the closure and post closure activities, monitor the site, collect samples and prepare inspection reports, provide for the treatment of leachate and maintenance of the leachate collection system, construct and maintain the final cover, and control methane gas. The operator is also required to adjust the estimates, as well as contributions to the account, as laws and closure designs change. Adjustments for inflation are also required. It should be noted that the department is party to the trust account agreement and may withdraw funds from the escrow account to carry out closure activities if the owner fails to do so. Further, the operator is not permitted to withdraw from the account except as authorized by the department.

Leachate Management

Section 401.6(B) 18, 401.7(A) 7, 8 and 12, 401.8(A) 4

Monitoring and controlling of leachate is required as a part of normal operation procedures and is extended to the closure and post closure periods. The leachate collection and treatment systems are to be monitored regularly, at a frequency determined by the department and leachate quality and the leak detection systems are to be monitored quarterly or until the department approves a decrease or discontinuance in monitoring.

Gas Management

Section 401.7(A) 7, 8 and 12, 401.8(a) 3

Gas monitoring and control, like leachate control, is required as part of normal operating procedures and is continued on a quarterly basis throughout the post closure period. The design of the monitoring program and collection system is not specified by the department.

Cover and Slope Stabilization

Section 401.7(C)

Placement of final cover is required over areas where solid waste has been deposited and over areas that were not properly closed in the past. The final cover must be sloped

between 5 and 33 percent and the slopes must be designed to prevent erosion of the cover. The final cover must also be seeded as soon as possible to promote evapotranspiration and prevent erosion.

The structural components of the final cover vary depending upon whether or not the site is an attenuation or containment type landfill. The requirements are as follows:

Attenuation Landfill Final Cover

Final cover for an attenuation landfill is required to be of at least 18 inches of compacted, well graded soil containing a minimum of 35% fines or native marine clay with a maximum permeability of 5×10^{-7} cm/s. Over this layer, six inches of soil, capable of sustaining grass growth, is required.

Containment Landfill Final Cover

Final cover for a containment landfill is required to be a composite (synthetic and soil) liner. Requirements for the synthetic liner as a component in a cover are not specified in the regulations. However, as a liner, the synthetic membrane must be constructed of high density polyethylene and no less than 80 mils in thickness. This liner must be underlain by 24 inches of well-graded soil containing a minimum of 35% fines or by native marine clay with a permeability less than or equal to the permeability of the primary liner. As a

minimum, the permeability of the cover is required to be of 5×10^{-7} cm/s or less. The upper layer of the final cover may consist of either 12 inches of sand and 12 inches of soil capable of sustaining vegetation, or a geonet and an unspecified (determined on a case-by-case basis) thickness of soil capable of sustaining growth.

Groundwater Monitoring

Section 401.6(C) 1 and 2, 401.8(A) 1

Comprehensive monitoring of groundwater is required as part of initial site investigations, operational procedures and closure activities. Sample of monitoring wells, as an extension of site operating activities, is required on a quarterly basis throughout the post closure period. The regulations pertaining to groundwater monitoring specify: well locations, installation methods, methods to evaluate the wells, maintenance requirements and parameters to be included. Baseline monitoring programs must also be established and corrective action is required if statistically significant increases in baseline levels are noted. Given the lengthy details of the groundwater monitoring component of the regulations, readers are referred specifically to Section 401.6(C) for a complete description of the requirements.

Land-Use Restrictions

Section 401.7(A) 15, 401.7(F)

Decisions with respect to the final end use of a closed landfill site are left to the site owner; however, the uses must be compatible with the final cover system and may not include: agricultural activities, excavation of soil or waste, or the establishment of any structures within 100 feet of the waste deposit area.

Also in line with land-use considerations is the requirement to register the closed sites at the Registry of Deeds. This is required in order that potential purchasers of land will be made aware of previous land-use at the site they wish to buy. The information to be recorded at the registry office must include: the type of facility operated, dates of operation and closure, descriptions of the waste location depth and composition, and the location of asbestos containing materials if such materials have been deposited in the site. The regulations also require that the deed restrict land-use at the closed site such that the final cover, liner, monitoring or other components of the closure system are not disturbed without prior written approval of the department.

3.2.3 New York Department of Environmental Conservation

The state of New York has developed comprehensive waste management regulations which came into effect December, 1988. The landfill component of the regulations includes such things as: siting, design, construction, operation, closure requirements, planning and application procedures, quality control/assurance controls, and surety or financial responsibility requirements.

The closure requirements contained in the new regulations are both performance and design based. The following paragraphs describe the key elements of the closure requirements:

Closure Planning Requirements

Section 360.2.7(d), 360-2.15(a)

When an operator applies for a permit to construct a new landfill or expand an existing site, the application must contain a closure plan. In order to develop an acceptable closure plan, the department requires that hydrogeologic conditions, the extent of explosive gas migration, the release of leachate and presence of vectors, be investigated.

Post Closure Period

Section 360.2-15(i)(4) and (7)

The New York Department of Environmental Conservation requires that the landfill post closure period extend for a minimum of 30 years. During this time, annual summary reports containing information regarding monitoring and inspection activities are required. This summary must include annual baseline data and quarterly monitoring results of leachate, surface water and groundwater sampling.

The regulations also require the site operator to prepare a post closure monitoring and maintenance manual. This document is meant to provide instructions and procedures for monitoring leachate, as well as sampling analysis and maintenance of all components of the closure system (gas management system, cover, vegetation, erosion controls).

Financial Assurance and Closure Cost Estimates

Section 360-1.12, 360-9.3

There are no specific provisions in the regulations requiring that a site operator develop cost estimates for closure activities nor is there a provision requiring operators to set aside money to finance closure. There are provisions stating that surety may be required, in a general sense and that surety will be

required to cover the cost of closure, if the site owner and operator are not one in the same.

Leachate Management

Section 360-2.15(i) 4, and 5

Leachate management during the post closure period is more or less a continuation of the activities carried out during the operational phase. That is, the collection and treatment of leachate is required either on-site or at an approved off-site facility. In the closure phase, maintenance of the leachate collection system and leachate treatment is required as long as the leachate is capable of impacting the environment. Quarterly monitoring of leachate is required for a minimum of five years. After five years, the department has the option to decrease or alter monitoring requirements, and will continue to evaluate monitoring results and requirements in five-year increments.

Gas Management

Section 350-2.15(a)(2), (c) through (f)

Gas venting systems are required at all facilities upon site closure. The systems must be designed to prevent the accumulation of gas in concentrations greater than 25% of the lower explosive limit. They should also be designed so that vegetation

on the cover or off-site is not damaged. Perimeter gas collection systems are required if monitoring reveals that the gas poses a hazard to health, safety or property. The collection system must be tied into low permeability soil, bedrock or the seasonally low groundwater table to prevent lateral migration. Specific regulations respecting gas management, if an active gas recovery system is installed, are provided in Section 360-2.17.

Cover and Slope Stabilization

Section 360-15(b)(i) 1, 2, 3

The final cover required in the New York regulations consists of three distinct layers; a gas venting layer, a hydraulic barrier and a protective layer. The bottom layer, bound between two filters, is meant to act as a gas venting layer; it is required to be a minimum of twelve inches thick and have a minimum permeability of 1×10^{-3} cm/s. Above this is a hydraulic layer which limits infiltration. The layer must be a minimum of 18 inches thick with a maximum permeability of 1×10^{-7} cm/s. The hydraulic barrier may also be constructed of a geomembrane. If selected, the geomembrane must be at least 40 mils thick and have a maximum permeability of 1×10^{-12} cm/s. It must also be able to resist chemicals in the waste and physical stresses and forces from settlement. Regardless of the material used to limit infiltration, slopes between 4 and 33 percent, to encourage run-off, are required.

The uppermost layer, the protective layer, is comprised of 24 inches of soil and above that, six inches of topsoil capable of sustaining vegetative growth. Where the underlying hydraulic barrier is comprised of soil, the function of the protective layer is to protect the hydraulic barrier from drying and cracking, frost action and root penetration. It must also be stable and able to resist erosion. The protective barrier over a synthetic hydraulic barrier provides much the same function except it does not need to protect the underlying material from desiccation. However, the bottom six inches of the protective layer should be reasonably free from stones so as not to damage the geomembrane.

Groundwater Monitoring

Section 360-2.11 and 360-2.15(i)4

Groundwater monitoring programs are typically conducted as part of site operation and are then required on a quarterly basis throughout the post closure period. The department may alter monitoring requirements based on the results received after the first five-year monitoring period.

The requirements of the monitoring program are lengthy and detailed and, as such, the reader is referred to Section 360-2.11 for a complete description. The section defines site hydrogeologic investigation requirements, specific requirements for

reporting and monitoring, as well as approved testing and construction methods.

Land-Use Restrictions

Section 360-2.7(d)(4)

Final use activities at closed landfills are not specified in the regulations. However, the regulations do require that end-use activities conform to landscaping plans and that they do not adversely affect the final cover.

3.2.4 Canadian Jurisdictions

Each provincial department of environment was contacted to determine if they had regulations, policies and/or guidelines pertaining to landfill closure. Only three provinces: Ontario, Saskatchewan and Alberta were identified as having regulations that made reference to the closure of landfills. Upon review, it was determined that the references were limited to specifying the depth of final cover and vegetative requirements. The seven remaining provinces have internal policies and general guidelines for the closure of landfills.

Of the three provinces with closure regulations, the Ontario Ministry of the Environment has the most extensive program

for the closure of landfills. In Ontario, solid waste management is provided for by Regulation 309 under the Environmental Protection Act. The Regulation contains definitions and general information regarding landfill location, maintenance and operation. With respect to closure, the regulation only stipulates that a final cover of cover material be placed on the completed fill. Although the Regulation does not have extensive closure requirements, the Ontario Ministry has developed internal policies and guidelines that provide specific requirements regarding landfill closure. These include: guidelines for the establishment, operation, management maintenance and closure of landfill sites, guidelines assessing methane hazards from landfill sites and guidelines for resolution of groundwater quality interference problems. The internal policies also relate to land-use near or on landfills and dumps, registration of land disposal sites and financial assurance for decommissioning, clean-up or rehabilitation of disposal sites. Further, it should be noted that the guidelines and policies reflect the Ministery's somewhat unique philosophy with respect to closure. In Ontario, final cover is not intended to prevent water infiltration, but to permit controlled infiltration in order that garbage decomposition can proceed at a pace which will permit their dispersal into the environment at safe levels without creating adverse effects.

In Ontario, "Guidelines for the Establishment, Operation, Management Maintenance and Closure of Landfill Sites" provides the desirable requirements to be employed at any waste disposal

landfilling site (proposed or existing). The guidelines stipulate that "closure should include grading, compacting and the covering of waste with a minimum of 60-100 cm of compacted cover material. The compaction density was not stipulated. The top of the site should be sloped to promote run-off. Revegetation should be undertaken to reduce run-off, infiltration, erosion and to promote evapotranspiration. The guidelines also make reference to the need for public information. Posting signs at the entrance of the landfill informing of closure activities and rodent control is required.

The Ontario "Guidelines for Assessing Methane Hazards from Landfill Sites" provides information regarding the migration of methane from landfills. The guidelines indicate that the preferred method of dealing with gas migration is to provide an adequate buffer that will allow for natural attenuation of the gas. A suggested buffer zone is calculated by multiplying the depth of landfill between the ground surface and the water table by a factor of ten. Very general information is also provided on gas control system (passive and active) and monitoring requirements.

The Ontario Ministry of Environment's internal policy on "Land-Use on or Near Landfills and Dumps" deals with the impact on land-use at or near an active or closed disposal facility, from leachate, surface run-off, ground settlement, visual impact, sources of contamination, and gas generation. The policy stipulates that "no land-use may take place within 30 metres of the

perimeter of a closed fill area, where technical controls for leachate and gas are required". The required distance may be reduced to 20 metres if only gas control is necessary. Land-use beyond 30 metres and within 500 metres of a fill area requires that the developer evaluate the presence and impact of any adverse environmental effects of risks to health and safety and that necessary remedial measures be taken. Land-use beyond 500 metres of a fill area does not require engineering studies unless the area is composed of fractured rock or sand.

The Ontario Ministry's policy regarding "Registration of Title on Certificates of Approval for Waste Disposal Sites" is designed to ensure that the general public may become informed about the use of municipally or privately owned land for waste disposal sites. As part of obtaining a certificate or provisional certificate of approval to operate a landfill, the certificate holder must register the disposal land site and the buffer zone within 60 days under the Land Titles Act or the Registry Act, thus when the site is closed, it has already been registered.

Recipients of orders and approvals to operate land waste disposal sites, issued under the Ontario Environmental Protection Act, must provide financial assurance at private landfills and/or sites with capacities greater than 40,000 cubic metres or serve more than 1,500 people. This assurance is required to ensure funds are available for future decommissioning, clean-up, rehabilitation and decontamination activities.

In Saskatchewan, solid waste management is provided for by the Refuse Management Regulation under the Environmental Management and Protection Act. The only reference to closure in the regulation is that the final cover must consist of one-half metre of compacted material. The closure of landfills is evaluated by the Saskatchewan Department of Environment on a case-by-case basis. There are no requirements to register land used for a disposal site; however, the department has an inventory of abandoned sites obtained during the abandoned dump site study, carried out by the provincial and federal environmental agencies.

Under the Solid Waste Regulation in Alberta, two metres of compacted clay, top soil and vegetation are required to cap and close the landfill. Permeability specifications are not provided. Groundwater is monitored by the Groundwater Protection Branch, but is only undertaken at landfills under the recommendation of the Alberta Board of Health. The Board of Health will not recommend monitoring landfills unless complaints are made by adjacent property holders. Former disposal sites are registered at the registry office as "restricted land-use" properties. For example, enclosed buildings may not be constructed on former disposal sites.

The province of Prince Edward Island does not have regulations regarding landfill closure. They have internal policies that require two feet of capping (no permeability specification) and regrading on closed landfill sites. The groundwater and leachate must be monitored three to five times a

year. The land on which the disposal site is located must be registered at the provincial registry office.

In Newfoundland, solid waste management is provided for under the Waste Material Disposal Act. The Act does not contain regulations pertaining to the closure of landfills; however, the Department of the Environment has internal policies and guidelines related to specific aspects of landfill closure. These policies require leachate and groundwater monitoring during the last year of the disposal site operations, and the placement of a final cover of one metre of compacted clay. Land used for the disposal of solid waste must be registered with their land-use atlas.

In Manitoba, solid waste management is covered under the Waste Disposal Ground Regulation. The regulation does not stipulate landfill closure; however, amendments to the regulation are in process which will include closure. The Manitoba Department of Environment has an in-house policy that a closed landfill requires two feet of compacted clay as a cover. In addition, former disposal sites must be registered at the land title office.

The province of Nova Scotia does not have a regulation for the closure of landfills. They have an in-house policy that recommends that landfills be capped with one metre of material (permeability is not specified). The department has identified 210 abandoned landfills and dumps and registered them with all

municipal planning agencies in order to control land-use of closed sites.

The province of Quebec does not have regulations regarding landfill closure, but are in the process of developing regulations. Quebec does not require that land used as a disposal site be registered; however, they do prohibit the construction of anything on former disposal sites for a period of 25 years.

Environment Canada does not have regulations regarding landfill closures. Guidelines and a Code of Good Practice were developed in the 70's for the closure of landfills and dumps. This information identified the principals required for the closure of landfills, such as cover, gas and leachate collection, but are very general and do not reflect state-of-the-art technology.

3.2.5 Final Cover Specifications

In the course of the literature review, it was determined that the purpose of a final cover is to limit infiltration of precipitation into the decomposing waste. It was also determined that cover systems may range between a minimum of two layers to six or seven layers, with each layer performing a particular function. The placement of sound final cover may be the single most effective activity carried out in closure in terms of environmental protection. Most regulatory agencies recognize this and typically

specify cover requirements in detail as design standards, to ensure cover objectives are met. Table 3-3 is provided to illustrate the various cover systems required by a number of Canadian and American regulatory agencies.

In terms of overall thickness and number of layers, the state of Wisconsin requires the most comprehensive final cover system with six layers which amount to a total of six and one half feet of cover. Aside from the cover requirements in the Canadian jurisdictions, Pennsylvania required the least in their cover system. Interestingly, however, Pennsylvania specified a double liner as part of their landfill design requirements. Maine was the only jurisdiction to require a composite liner. Illinois was the only jurisdiction requiring only two layers in the cover system, but, in terms of overall thickness (six feet), were second only to Wisconsin.

TABLE 3-3
Final Cover Designs as Required by Regulation

	COVER SYSTEM COMPONENTS*						
	Filter	Foundation/Gas Venting Layer	Filter	Hydraulic Barrier	Drainage Layer	Filter	Protective Cap
UNITED STATES							
Kentucky	✓	12" @ 1 x 10^{-3} cm/s	✓	18" @ 1 X 10^{-7} cm/s or 40 mil geomembrane @ 1 x 10^{-12} cm/s	12" @ 1 x 10^{-3} cm/s	NR	36" soil
Illinois	NR	NR	NR	36" @ 1 x 10^{-7} cm/s or geomembrane	NR	NR	36" soil
Maine	NR	NR	NR	geomembrane over 24" soil - 35% fines	NR	NR	12" sand and 12" topsoil
Minnesota	NR	✓	NR	24" @ 1 x 10^{-6} cm/s or geomembrane	6" gravel	NR	12" soil 6" topsoil
New York	✓	12" @ 1 x 10^{-3} cm/s	✓	18" @ 1 x 10^{-7} cm/s or 60 mil geomembrane	NR	NR	24" soil 6" topsoil
Pennsylvania	NR	NR	NR	12" clay or 30 mil geomembrane	✓	NR	24" soil
Wisconsin	NR	6" coarse soil and 12" @ 1 x 10^{-3} cm/s	✓	24" @ 1 x 10^{-7} cm/s	12" @ 1 x 10^{-3} cm/s	✓	18" soil 6" topsoil
CANADA							
Alberta	NR	NR	NR	2.0 m clay	NR	NR	✓
Saskatchewan	NR	NR	NR	0.5 m clay	NR	NR	NR
Ontario	NR	NR	NR	0.6 - 1.0 m clay	NR	NR	✓

* - See section 2.2.4.3 for a description of the various components.
✓ - Required but not specified
NR - Not required

4.0 REVIEW OF REGULATIONS PERTAINING TO THE CLOSURE OF NON-CONTAINMENT LANDFILLS IN OTHER JURISDICTIONS

Over the next five years, it is expected that more than 200 disposal sites in New Brunswick, each varying greatly in size, remoteness and location, will have to be closed in such a manner that they do not constitute a significant threat to the environment or public health and safety. Further, because these sites were not established in accordance with siting criteria or design guidelines, the steps necessary to properly close the sites will differ from location to location. Given the magnitude and complexity of this task, it is apparent that there will be a need to set out a plan for the closure of these non-containment landfills.

This section presents the regulatory requirements as well as guidelines used by several agencies in approaching the issue of closing non-engineered dumpsites. Illinois, Maine and Wisconsin, each with relatively progressive waste management programs, were contacted in order to determine how they were dealing with the closure issue. In this review, it was determined that most jurisdictions, including the state of Maine, which has implemented a comprehensive closure priorization program, set out closure requirements for dumps on a case-by-case basis.

4.1 Illinois Environmental Protection Agency

The state of Illinois has implemented comprehensive regulations for non-hazardous waste disposal sites, which address all aspects of disposal site management, including closure. New disposal facilities and expansions of existing sites will be required to meet the requirements set out in the new regulations. However, the regulations (operation, closure) that will apply to existing sites will depend on the length of time, after the effective date of the regulations, they intend to remain open.

Essentially, all existing operators in Illinois will have to assess the ability of their site to meet the new requirements and whether or not they wish to invest the time, effort and money in site upgrading in order to comply with the new regulations. For example, an owner/operator with a relatively new site situated in a suitable hydrogeological environment may wish to install a leachate collection system and continue to operate indefinitely. In this case, the State will require the site to be operated and closed in accordance with the new regulations. An operator, with a less ideal site able to meet certain groundwater protection criteria, but unable to retrofit a leachate collection system, may be permitted to stay open up to seven years providing certain operating restrictions are followed. Again, the site in this instance would be subject to the closure provisions in the new regulations.

Finally, a site that cannot meet any of the new requirements or is scheduled for closure within two years of the effective date of the new regulations, may remain open two years or until the scheduled closure date, whichever comes first. Operating and closure requirements at these sites will be in accordance with the pre-1990 solid waste regulations. The following paragraphs describe the closure regulations that will be applied to existing sites that will close within the next two years.

The existing regulations require that closure be carried out in such a manner that minimizes the need for further maintenance and controls, and minimizes or eliminates post closure releases of waste decomposition products to ground and surface water and the atmosphere, in order that the threat to human health and environment is prevented. More specifically, the regulations require that:

- the site be covered with two feet of suitable compacted material,
- gas, water and settlement be monitored for three years after closure,
- remediation be undertaken to correct or mitigate any gas, water and settlement problems, which may occur during that period, and

- a complete and detailed description of the site be filed with the appropriate county land recording authority.

The closure regulations also require that sites permitted between 1985 and 1990 prepare and submit detailed closure and post closure plans with comprehensive cost estimates. The regulations suggested that the closure estimate should include (at a minimum) the cost of: obtaining, hauling, placing and grading the cover, establishing vegetation, and installing gas controls. Similarly the post closure estimate is to include (at a minimum) the cost of groundwater monitoring (number of points, parameters and frequency) and cover stabilization. The estimates are to be revised every two years and the operator is required to obtain financial assurance to fund closure and post closure activities. Trust funds, surety bonds, letter of credit, closure insurance or self insurance are each acceptable forms of financial assurance.

4.2 Maine Department of Environmental Protection

The state of Maine has adopted a comprehensive waste management regulation that addresses the issue of landfill closures. However, these provisions apply only to new sites or sites that are permitted (and upgraded) under these regulations.

Therefore, the department has developed a program to deal with the closure of sites not covered by the new regulations.

The landfill closure/remediation program was established in 1987 to provide technical guidance and financial assistance to municipalities owning active and/or closed/abandoned disposal sites. The program was implemented to "accomplish the prompt closure of solid waste landfills, which, through inappropriate siting, inadequate design and construction, or improper operation pose an actual or potential hazard to the environment and public health". Under this program, sites would be ranked in terms of environmental threat posed by the site in two categories (open and closed/abandoned) based on the existing knowledge of the site. This ranking, in turn, would establish the priority in which they would be subjected to an environmental evaluation under the direction of the department. The evaluation would then allow the most appropriate closure and/or site remediation program to be developed. Finally, once the plan was developed, the municipality would then be required to raise their portion of the funds needed to implement the plan. Clearly, one of the key benefits of this systematic approach is that the sites posing the greatest environmental threats will get the attention and funding sooner, rather than later.

The following paragraphs describe in further detail some of the relevant components of the program, such as ranking criteria, funding and status of the program.

Ranking Criteria

To determine, in a logical fashion, the order in which sites are to be subjected to an environmental evaluation, criteria to evaluate the disposal sites and a scoring system were developed. For closed or abandoned sites, ranking criteria included: the size of the site, population served, documented groundwater contamination, documented surface water contamination, acceptance of special waste, distance to surface water and site location relative to gravel aquifers. Each criteria was given a point value (i.e. groundwater contamination 20; acceptance of special waste 10) for a possible score of 125 points. The site was then evaluated and scored in light of the criteria.

The criteria used to evaluate the active sites included: size, threat to public or private drinking water supply, potential or documented threat to groundwater supply, threat to surface water, open burning, improper cover and compaction, and acceptance of unlicensed special wastes. Similarly, each criteria was given a point value and the site evaluated and scored in light of the

criteria; however, the maximum score for an active site was set at 105.

The preliminary evaluations carried out at the closed and active sites were undertaken using existing information and previously completed studies. The evaluations were then used to assist the department in establishing priorities for further assessments, detailed evaluations and decisions on how the funding would be dispersed.

Financial Assistance

Financial assistance is available to the various municipalities for: environmental site evaluations, planning of closure or remediation activities and implementation of the plans at active or closed disposal sites. A total of thirteen million dollars, with $3.5 million for evaluations and planning and $9.5 million for actual implementation, has been designated for the program. The funds will generally be disbursed in accordance with the initial site rankings (i.e. highest ranked sites will undergo evaluation and closure first).

Funding available to the municipalities will be based on a percentage of their project costs. In the case of closure activities, 75% of the cost is fundable, and in the case of site

remediation, 90% of the cost is fundable. The department has prepared a list of items that are eligible and ineligible for funding. Cost sharable (eligible expenses) items include: engineering and design of a closure plan; liners; excavation work; installation of wells; gas venting; leachate control; erosion control; testing and quality control; and the cost of preparing funding applications and closure certification applications. Non-eligible items include: cost of land; normal repair of equipment used in closure (if closure is conducted by the municipality); removal of tires and white goods; legal fees or licensing of alternative waste management facilities.

Current Status

At present, the closed/abandoned and active municipal sites in Maine have been ranked. Site evaluations and closure plans are also being developed and closure and remediation activities are underway. However, because of budget restraints, provision of financial assistance to the municipalities to implement closure activities has been somewhat limited. As a result, closure activities have been cut back and now appear to be a function of environmental as well as economic constraints.

In discussions with regulatory officials, it was determined that, because of the budget cutbacks, the extent of

closure activities often vary as site size and distance from a well varies. For example, a small site, say five acres in size or serving in the order of 3,000 people which is 1,000 feet beyond a private well, would require only minimum closure requirements. Minimum closure requirements would include:

- registration of closure plan
- establishment of site boundaries
- ensuring the slopes of the site are stable
- placement of a cover comprised of a gas migration layer, 18 inches of clay and 6 inches of a protective cover to sustain vegetation

At larger non-engineered municipal sites, where there is concern regarding water supply contamination or the presence of industrial type waste, the closure activities identified in the preceding paragraph and hydrogeological investigations will be required. The department feels that, prior to implementing any groundwater or leachate control systems, a monitoring program must first be conducted in order to justify the need and the cost.

With respect to land-use at closed sites, the department discourages active use but will allow low impact type activities. They also prohibit the establishment of a structure within 100 feet of the toe of the slope of the disposal area. Finally, while the

department does control land-use at the closed site, they do not control land-use adjacent to the site.

4.3 Wisconsin Department of Natural Resources

Wisconsin, a recognized leader in waste management, has recently adopted new landfill regulations, NR Code 500. As with most new regulations, they cover a wide range of issues from siting, design, operation and closure. As a result of NR Code 500, a large number of disposal sites in Wisconsin will be closed over the next few years. The state does not have an official closure program; however, technical advisors at the department have set out general closure procedures and requirements to assist existing site operators in planning and carrying out closure activities.

Closure activities at disposal sites are undertaken to ensure human health and safety, as well as the environment, are protected. In particular, the discharge of leachate and methane gas from closed sites is of concern. In Wisconsin, the manner and degree to which leachate and methane from closed sites is managed vary as the sites vary. As a rule, closure requirements vary according to size, whether or not groundwater problems at the site have existed in the past, and proximity of the site to wells. Generally, site size and usage help define general closure requirements. The presence of groundwater problems and site

isolation are used to define the more specific closure requirements.

Small Sites

Sites containing less than 50,000 cubic yards of waste or serving less than 2,500 people may be considered as small sized sites. These sites have historically been allowed to burn waste, and, as a result, are somewhat isolated and usually more than 1,200 feet from nearest well. Further, these small sites have served small rural communities and usually contain only residential waste. Because of the relatively benign nature of these sites, the basic closure requirement will be the placement of a cap over the site. The site will have to be sloped and graded to promote run-off, and a cap consisting of two feet of fine grained soil, overlain by six inches of topsoil, which can sustain vegetation, will be required. In terms of gas control, the department has suggested that the gas be allowed to dissipate naturally. This approach is felt to be acceptable because significant gas generation is not anticipated and because the sites are somewhat remote. The basic closure procedure may include extras such as groundwater monitoring, if a small site is in an environmentally sensitive area or within 1,200 feet of a well.

Medium Sites

Sites containing greater than 50,000 cubic yards of waste or serving populations larger than 5,000 people may be considered as medium sized sites. These sites have typically accepted residential, commercial, light manufacturing and industrial type wastes. Because of their size, the nature of the waste accepted at the sites and because the waste was not routinely burned as a method of operating, closure activities at these sites are usually more comprehensive.

For example, most sites of this size have either had on-site groundwater contamination problems or are within 1,200 feet of a well. Therefore, groundwater monitoring at these sites is often required. Monitoring of methane gas at these sites is also required. If excessive levels are found at the property boundary, then passive gas venting systems are required. Active gas extraction systems are required if volatile organic contaminants are found in the groundwater.

Finally, the department requires sites of this size to be capped in the same manner as the engineered sites. A multi-layered cover, as specified in Table 3-3, is required.

Large Sites

Sites with capacities greater than 500,000 cubic yards and serving between 10,000 and 50,000 people may be considered as large sized sites. These sites are typically engineered sites and must meet the requirements of NR Code 500. As such, these sites are closed in accordance with the new landfill regulations.

Land-use activities at closed sites, regardless of their size, is somewhat restricted. Specifically, agricultural uses, construction upon, or excavation of closed sites is not permitted. Land-use surrounding the closed sites is not restricted per se; however, construction of a well within 1,200 feet of a closed site requires special approval. In discussion with officials at the department, it was determined that this approval is not usually given.

Finally, in an attempt to assist potential land buyers in avoiding the pitfalls of inadvertently buying a closed site, the department requires landfill site owners to submit closure information to District Land Offices where it is entered into a 'registry' of closed sites. While this list is available to help land buyers, lawyers are not obligated to search this list as they conduct title searches for their clients.

5.0 DEVELOPING A REGISTRY OF CLOSED SITES

As discussed in the literature review, final land-use activities at closed landfills are somewhat limited. In New Brunswick, for example, the Health Regulations prohibit construction on closed sites for a period of 25 years after site closure. Further, where active or high impact land-uses, such as construction, are contemplated, many special safety and design considerations are necessary. Therefore, it is expected that, if given the choice, most prospective land buyers would rather not have to contend with these restrictions. However, there is no mechanism in place in the province to inform prospective land buyers of past land-use activities that could potentially restrict future use of the site.

Given the unnecessary economic hardship and environmental problems that could be caused by unknowingly purchasing a closed site, and because more than 200 sites will be closed shortly, it appears that there is a need to develop a method of informing prospective land buyers. A number of approaches are available to identify closed landfill sites and make their location known to prospective land purchases. These vary in effectiveness and in the amount of effort required to put them in place.

The simplest would be to develop a registry of such sites and publicize it widely. While this could be put in place quickly

and with a minimum of effort, it has several serious drawbacks. In its simplest form, there may be no legislation to require site owners/operators to register their sites on closure. Many sites may not be registered, either intentionally or because of changes in administrative priorities which give the program a low profile. Furthermore, it is difficult to ensure the effective use of the list, particularly after the initial intensive publicity associated with its development.

A second approach that addresses these shortcomings is to prepare legislation requiring landfill sites to be registered upon closure. This will give the list legal status. A program could then be worked out with the New Brunswick Law Society (NBLS) to include the requirements to search list in the practice notes used by lawyers when searching a legal title.

A third approach, which would also be combined with a legal requirement for registration, would be to have the existence of a closed landfill site on the property deed. This would be an alternate way of ensuring that a title search would determine if land had been used as a landfill. However, it was determined from discussions with the NBLS that, in recent years, there has been a shift away from placing notes, encumbrances and conveyances on deeds. The trend has been to move toward keeping the deeds in a simple and standardized format and therefore, this option would be less likely.

The establishment of a registry for mandatory use by lawyers by legislation and a requirement to search the list appears to be the most promising approach and is discussed in more detail in the following section. Developing an inventory of sites as an information/notification mechanism would require that:

-- the exact location of closed, or soon to be closed sites, be identified and compiled into a comprehensive listing,
-- the list was updated frequently,
-- the existence of the list and its purpose would have to be made known, and
-- the list be readily accessible.

If this information is to serve the desired objective of protecting land buyers, there must be legislation to: establish the list as a tool in the land registry office and to require the list be maintained. In addition, practising lawyers would have to be made aware of its existence and be required to consult the list in title searches. This is because it is the lawyers performing title searches in land purchase transactions that provide the link between the inventory of sites and prospective land buyers.

The decision to establish a system to inform land buyers would have a number of significant legal implications which directly impact practising lawyers. For this reason, the NBLS

should be consulted concerning the development and legal aspects of the inventory. This organization would be helpful because they are knowledgeable of the various components of title searches and represent the people actually using the inventory. They have a standards committee (comprised of real estate lawyers and a lawyer/legal surveyor) to deal with the practice of law as it relates to land title issues, and they have investigated a similar type of inventory for underground storage tanks.

If an inventory listing is developed, the department may also wish to involve the department of municipal affairs because of the land-use planning implications related to closed dumps. Involvement of the NBGIC is also recommended since the province is now moving toward a land reform registry system and away from the somewhat outdated grantor/grantee title system. Essentially, the land reform registry maintains information pertaining to land on the basis of a property identification number (one number to each property) rather than on the basis of names. All transactions for a given property would be recorded under one identification number. The current system (grantor/grantee) requires that each individual transaction relating to a piece of property be searched on the basis of names.

As part of the move toward the land reform registry, NBGIC is responsible for operating land information centres which enables the public, surveyors, lawyers, and real estate agents to

access huge information databases. To access information about a particular property, either the owner's name and location of the property, or its property identification number (PID) is entered into the computer and information about the site is recalled. If the department of environment so desires, NBGIC would be willing to include information in this database that notes whether or not particular properties at one time served as a disposal site. They would require the department to provide the disposal site PID numbers and to provide some technical information; however, the NBGIC estimates that the cost of adding this information would be minimal.

If the department wishes to proceed with a system of registering closed disposal sites, a first step would be to meet with these agencies and groups most directly affected by the system. Those directly involved should include: the departments of environment, municipal affairs and justice, the law society, and NBGIC. The issues that should be discussed would include:

- Who is best suited to administer the program?
- Which closed sites will be included (only sites closed as a result of the solid waste program or all closed sites)?
- Which mechanism is best?
- What legislative amendments will be necessary to establish the list as a registry tool?

- How will practising lawyers be advised of the policy?
- Who will identify the closed sites?
- How will the sites be identified (name, property identification number)?
- Who will upgrade and maintain the inventory?
- What format should the listing follow?
- How will the listing be distributed?
- Will a backup file with details of the disposal site operating history be required?

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